

Neural Simulation for Auricular Vagus Nerve Stimulation

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Abstract— Electromagnetic field simulations coupled with neural simulation were performed to characterize threshold values for stimulation of the auricular branch of the vagus nerve (ABVN) using anodic and cathodic pulses. Results show that bi-phasic cathodic pulses, besides the benefits of charge balance, are the pulses requiring the least amplitude to activate the modelled axons.

I. INTRODUCTION

Stimulation of the ABVN by small needle electrodes in the auricle gained importance as a treatment for acute and chronic pain, as well as for peripheral perfusion dysfunction [1]. Main shortcoming in ABVN stimulation is the unguided/empirical selection of both stimulation regions and parameters, leading to over- or understimulation. The relation between the electric potential distribution and actual stimulation of neurons is not always straightforward. Therefore, electromagnetic field simulations coupled with neural simulation is highly needed to understand and characterize the ABVN stimulation.

II. MATERIALS

Simulations were performed with Sim4Life (ZMT). We combined the electro-static solver for the electromagnetic simulation with the neural tissue models for the neural activation. The numerical model consisted of a realistic high resolution model of a human ear (resolution 3 mm), 3 electrodes, and a spatial model of major blood vessels and axons (Fig. 1). The Spatially

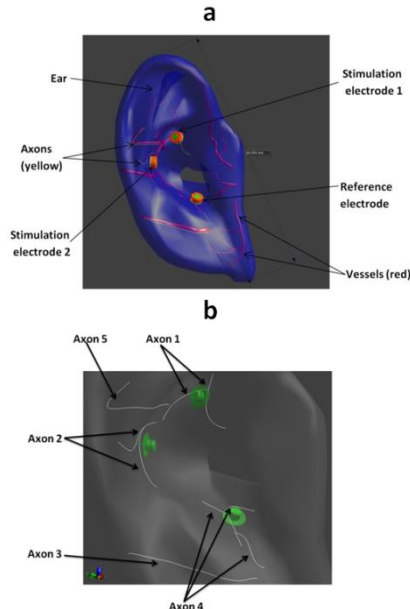


Figure 1. a) Auricle, vessels, axons, and the electrodes. b) Locations and shapes of the axons.

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Extended Nonlinear Node (SENN) [2] model was used to investigate transmembrane mechanisms. Positions of the axons were based on Peuker and Filler [3]. Simulation was performed using anodic and cathodic single cycle mono-phasic and bi-phasic pulses (amplitude 1 V, pulse width 1 ms). Skin and blood vessels conductivity was set to 0.2 S/m and 0.7 S/m, respectively. Threshold for depolarization, initial potential, fiber diameter, and the nodal gap were set to 80mV, -70 mV, 10 μ m, and 2.5 μ m, respectively.

III. RESULTS AND DISCUSSION

Table I shows the required pulse amplitude to activate the nerves as a function of the stimulation pattern. The voltage for each axon is related to the anodic mono-phasic voltage. Considering amplitude of 1 V, axon1, axon2 and axon4 are the activated axons (for the generation and propagation of the action potential), while axon3 and axon5 requires more amplitude to be activated. Axon 3 and axon5 are on the back of the ear and thus are less exposed to the electric field generated by the electrodes positioned in the front of the ear.

Bi-phasic pulses tend to require less amplitude to activate the nerves compared to the mono-phasic pulses for anodic stimulation (average value: 2.66 V for bi-phasic and 4.84 V for mono-phasic). This difference is less important when using the cathodic pulses (average value: 2.69 V for bi-phasic and 2.88 V for mono-phasic).

TABLE I. REDUCTION OF THE STIMULATION THRESHOLDS RELATED TO THE ANODIC MONO-PHASIC VOLTAGE

Threshold amplitude (V)	Axon1	Axon2	Axon3	Axon4	Axon5
Mono-phasic+	0.77	0.88	14	0.22	3.5
Bi-phasic+	37%	53%	57%	0%	-8%
Mono-phasic-	27%	50%	57%	-18%	-20%
Bi-phasic-	31%	52%	56%	4%	2%

IV. CONCLUSION

A realistic model of the ear including vessels and axons was developed. Results of simulation show that cathodic pulses, in general, require less amplitude than the anodic pulses. The cathodic bi-phasic is the pulse requiring less amplitude added to the fact that it is a charge balanced pulse.

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